

# **Active and Passive Sensing from Geosynchronous and Libration Orbits**

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## **1, Introduction**

The focus of the last decade's EOS and ESA missions has been earth observation from low earth orbit (LEO) typically 700-800 km, polar sun synchronous. LEO sun-synch orbits with wide-field of view sensors provide global coverage in a day. In addition, these orbits are low enough so that active sensors such as radars and lidars can operate within the available spacecraft power systems, amplifiers and detectors.

Despite the advantages of the LEO, there are a number of scientific problems that cannot be addressed from a "once a day" observational strategy. Alternate higher time resolution LEO approaches include: low inclination orbits such as that used by the Tropical Rainfall Measurement Mission (TRMM) or multiple-spacecraft missions such as is being proposed by the Global Precipitation Measurement (GPM). The disadvantage of the low inclination orbits is that they do not provide global coverage. The disadvantage of the multiple-spacecraft approach is that the time resolution is not increased significantly for each spacecraft launched. Thus for a 3 hour time resolution, eight spacecraft are required – increasing the observational cost and increasing the risk since each spacecraft must be fully operating to meet the measurement frequency requirements.

Other obvious choices for measurements are Mid Earth Orbit (MEO), geosynchronous and Lagrange orbits. Geosynchronous orbits have a period equal to a day. Geostationary orbits, a subset of the class of geosynchronous orbits, have the orbit plane aligned with the equator thus the spacecraft appears to hover above one point along the equator. Geostationary orbits (GEO) are used by communication satellites and are located roughly 36,000 km in altitude. NOAA places the GOES satellites into GEO orbit to monitor clouds, temperature and water vapor fields. Other nations have placed additional GOES-

type satellites in orbit. With about 5 satellites, coverage of the entire globe (equatorward of about  $60^\circ$  latitude) is possible. It is possible to get global images of the cloud/water vapor fields every 15 minutes using multiple satellites.

The Lagrange points L1-L5 are located much further from the earth than GEO points. Figure 1 shows the location of L1-L5 points. Only L4 and L5 are stable (also called the Trojan points) although it does not take much spacecraft fuel to stay at the meta-stable points L1 and L2. L1 and L2 are about 1.5 million km from earth and are clearly the most useful for observations. The DSCOVR (Triana) mission intends to make earth observations from L1, and a number of other missions currently take advantage of L1's location away from the earth's magnetic field in order to make solar wind, and microwave measurements.

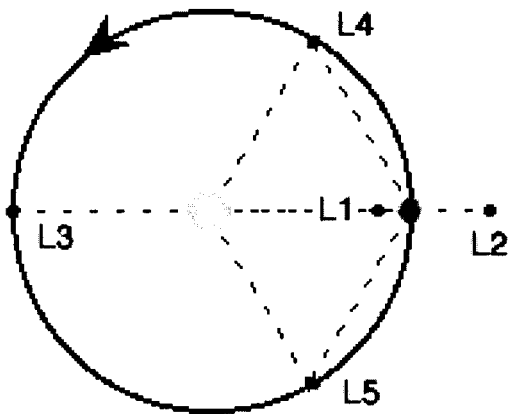


Figure 1. Location of the Lagrange points L1-L5 relative to the sun (center) and the earth. Taken from JPL's Basics of Spaceflight (<http://www.jpl.nasa.gov/basics>). All the Lagrange points are outside the lunar orbit

## 2. Science Requirements

There are a large number of phenomenon that occur at frequencies faster than can be resolved by one or two LEO observations per day. These phenomenon include severe storm outbreaks, fires, earthquakes, volcanic eruptions, pollutant releases, diurnal changes in the boundary layer, tidal effects, and release of pollutants. Figure 2 shows a relation between spatial and temporal scales for atmosphere, ocean and land surface processes as well as the resolution of atmospheric models. Generally, the larger the scale of the phenomena, the lower the frequency requirement for sampling. This is because the communication speed between various elements of the phenomena is determined by the

atmospheric/ocean circulation. There are exceptions to this rule, of course, such as atmospheric and ocean tides. Earthquakes and volcanic eruptions occur very suddenly, but represent the culmination of decadal to millennial period of stress buildup. The typical swath width of a synthetic aperture radar (SAR) system to monitor crustal deformation is 100's of km, resulting in revisit times of up to 8 days for specific targets with a single LEO satellite. A few LEO observations per day can be useful, but this will typically require a constellation of LEO SAR satellites.

The horizontal white line in Fig. 2 indicates the GEO and LEO (single spacecraft) time and space resolution capability. It is apparent from Figure 2 that a large number of phenomena cannot be resolved by LEO but can be sampled from GEO.

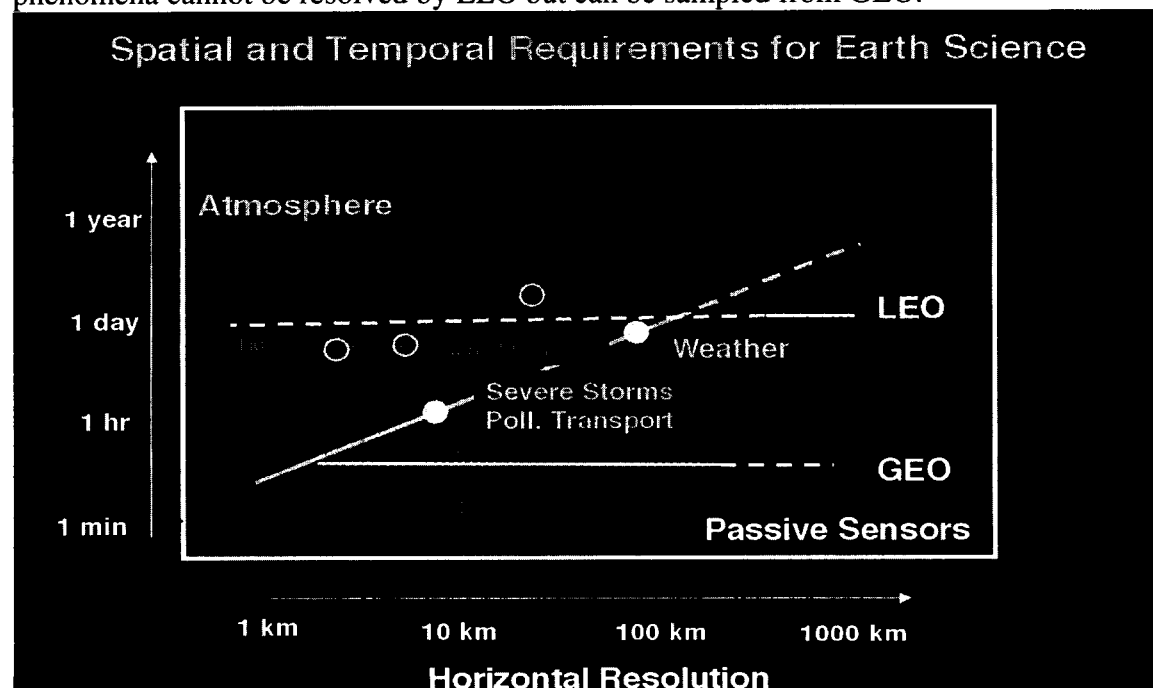


Figure 2. Spatial and temporal requirements for climate sciences. Generally, as the spatial scale decreases, the required time resolution increases. The main point is that LEO observations provide inadequate temporal coverage for a host of phenomena.

## 2.1 MEO

For frequent interferometric SAR measurements of crustal deformation, MEO may be the optimal choice for global coverage and frequent repeat with the minimal number of satellites. This occurs because the observable swath increases faster than the spacecraft velocity decreases, resulting in better coverage and therefore more frequent revisits. The severe drawbacks to this region of space is the presence of radiation belts.

## 2.2 GEO

Figure 2 suggests that GEO might be the solution to all earth observation. There are a number of disadvantages to GEO that are commonly articulated. 1) GEO can only sample about 1/5 of the earth, and can make measurements only equatorward of about 60° latitude so you must fly 5 GEO's minimum and give up polar observations. 2) GEO is also ~60 times further from the surface than LEO which precludes the use of active sensors. 3) GEO pixel resolution will be much larger than the equivalent LEO sensor pixel. Synthetic aperture radars in geosynchronous orbit, however, are feasible given a large antenna area (~30m) , and pixel resolution is actually greater because of increased dwell time.

With new technology, many of these disadvantages have disappeared.

- 1) Drifting GEO (either sub or super GEO orbits) will allow sampling of the whole globe in about a week or longer. This means that the satellite can go to "where the science is" and then move elsewhere. Of course, you still cannot produce global coverage in a day and the poles will not be covered.
- 2) Light weight telescopes can be used to provide equivalent LEO pixel resolution by staring. Thus, the GEO satellite can more than make up for the lack of photons. For example, at 7 km/sec, a LEO satellite has 1/7<sup>th</sup> of a second to gather light from a 1 km pixel. The same number of photons will be available in about 100 seconds from GEO. Another advantage of GEO is that if a cloud obscures a target point on the surface, the GEO observer can wait until the cloud moves, while a LEO satellite will have to wait 12-24 hours for another overpass.
- 3) Active lidar systems still seem outside the realm of current technology. For example, the  $1/r^2$  laws suggest that the GEO lidar must be at least 3600 times more powerful than its LEO cousin assuming that same detector system. However, with the GEO staring ability, and using modern photon counters, this factor can probably be reduced an order of magnitude or more.
- 4) Active SAR systems are feasible in the future if lightweight antenna technology matures such that antennas of 10's of meter scales are possible.

## 2.3 Lagrange Point L1

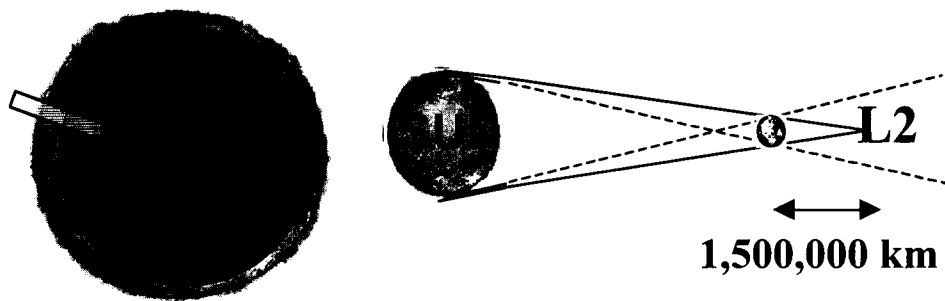
Triana/DSCOV<sup>R</sup> was built to make earth observations from L1. As viewed from L1, the earth is always in sunlit, thus L1 measurements are ideal for reflected sunlight observations such as those required to make aerosol and ozone measurements. In addition, the occasional lunar transit in the field of view provides an opportunity for

calibration. From L1, the earth occupies about  $1/2^\circ$  in the field of view thus high resolution observations require the use of telescopes and accurate pointing.

It is unfortunate that the Triana mission, scheduled for launch on the shuttle Colombia, may now never be launched. However, the utility of the L1 vantage point has been established and new missions should be proposed to make use L1.

## 2.4 Lagrange Point L2

The second Lagrange point has a unique advantage in that the Earth does not completely occult the sun (as shown in Figure 2). This novel geometry has a



*Figure 3. The geometry of the sun-earth system from L2 is shown. The earth does not completely occult the sun making solar occultation observations possible.*

significant advantage for earth observations. A large number of trace gases can be detected in the earth's atmosphere by detecting the solar absorption. This type of measurement is sometimes referred to as self calibrating since the base solar flux can be measured easily at the upper part of the limb. LEO measurements of stratospheric trace gases have been made using solar occultation by SAGE I, II and III, POAM, HALOE and most recently, SCIAMACHY. There are two disadvantages to LEO solar occultation measurements: First, there are infrequent sunrise and sunsets (usually  $\sim 7$  per day) for measurement. Second, to provide near global coverage, the satellite must be placed into an inclined orbit. This produces a measurement geometry such that it takes about a month to produce global coverage – the satellite measurement latitude sweeps slowly north or south during the measurement period..

Occultation from L2 remedies both of these problems. Global coverage could be produced in a single day with measurements down to about 8 km in altitude. Pre-engineering studies of such an occultation system have shown that technology is feasible.

### 3.0 Summary

The development of the LEO (EOS) missions has led the way to new technologies and new science discoveries. However, LEO measurements alone cannot cost effectively produce high time resolution measurements needed to move the science to the next level.

Both GEO and the Lagrange points, L1 and L2, provide vantage points that will allow higher time resolution measurements. GEO is currently being exploited by weather satellites, but the sensors currently operating at GEO do not provide the spatial or spectral resolution needed for atmospheric trace gas, ocean or land surface measurements. It is also may be possible to place active sensors in geostationary orbit. It seems clear, that the next era in earth observation and discovery will be opened by sensor systems operating beyond near earth orbit.